SUMMARY OF TALKS, DISCUSSIONS, FIELD TRIP, AND OUTSTANDING ISSUES

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Land subsidence, the loss of surface elevation as a result of the removal of subsurface support, affects every state in the United States. More than 17,000 mi^2 of land in the United States has been lowered by the various processes that produce land subsidence with annual costs from resulting flooding and structural damage that exceed $125 million. It is estimated that an additional $400 million is spent nationwide in attempts to control subsidence. Common causes of land subsidence include the removal of oil, gas, and water from underground reservoirs; dissolution of limestone aquifers (sinkholes); underground mining activities; drainage of organic soils; and hydrocompaction (the initial wetting of dry soils). Overdrafting of aquifers is the major cause of areally extensive land subsidence, and as ground-water pumping increases, land subsidence also will increase.

Land subsidence and its effects on engineering structures have been recognized for centuries, but it was not until this century that the processes that produce land subsidence were identified and understood. In 1928, while working with field data from a test of the Dakota Sandstone aquifer, O.E. Meinzer of the U.S. Geological Survey recognized the compressibility of aquifers. Around the same time, Karl Terzaghi, a soil scientist working at Harvard University, developed the one-dimensional consolidation theory that provided a quantitative means of predicting soil compaction resulting from the drainage of compressible soils. Thus, with the recognition of the compressibility of aquifers (Meinzer), and the development of a quantitative means of predicting soil compaction as a consequence of the reduction of intergranular pore pressure (Terzaghi), the theory of aquifer-system compaction was formed.

With the widespread availability of electric power in rural areas, and the advent of the deep turbine pump, ground-water withdrawals increased dramatically throughout the country in the 1940’s and 1950’s. Along with this unprecedented increase in pumpage, substantial amounts of land subsidence were observed in several areas of the United States, most notably in Arizona, California, and Texas. Beginning in 1955, under the direction of Joseph Poland, the Geological Survey began the “Mechanics of Aquifers Project,” which focused largely on the processes that resulted in land subsidence due to the withdrawal of ground water. This research team gained international renown as they advanced the scientific understanding of aquifer mechanics and land-subsidence theory. The results of field studies by members of this research group not only verified the validity of the application of Terzaghi’s consolidation theory to compressible aquifers, but they also provided definitions, methods of quantification, and confirmation of the interrelation among hydraulic head declines, aquifer-system compaction, and land subsidence. In addition to conducting pioneering research, this group also formed a “center of expertise,” providing a focal point within the Geological Survey for the dissemination of technology and scientific understanding in aquifer mechanics. However, when the “Mechanics of Aquifers Project” was phased out in 1984, the focal point for technology transfer no longer existed.

Interest among various state and local agencies in land subsidence has persisted, and the Geological Survey has continued to participate in a broad spectrum of cooperative and Federally funded projects in aquifer mechanics and land subsidence. These projects are designed to identify and monitor areas with the potential for land subsidence, to conduct basic research in the processes that control land subsidence and the development of earth fissures, as well as to develop new quantitative tools to predict aquifer-system deformation. In 1989 an ad hoc “Aquifer Mechanics and Subsidence Interest Group” (referred to herein as the “Subsidence Interest Group”) was formed to facilitate technology transfer and to provide a forum for the exchange of information and ideas among scientists actively working in subsidence and aquifer-mechanics-related projects. The Subsidence Interest Group is not focused solely on land subsidence resulting from ground-water withdrawals, although this is one of the primary areas of study for many of the group's members. Subsidence Interest Group members are also actively involved in studies of subsidence due to sinkhole collapse (karst), drainage of organic soils, geothermal development, and hydrocompaction. The group also is seeking to expand its expertise to include subsidence resulting from subsurface mining activities.

The first technical meeting of the Subsidence Interest Group was held at Phoenix, Arizona, in December 1989 and included formal presentations on the history of land subsidence studies as well as ongoing studies being done by the Geological Survey. As a result of this initial meeting, several new collaborative research efforts were begun. The second meeting of the group was held at Edwards Air Force Base, California, in November 1992, and included technical presentations of ongoing research and a field trip to view subsidence features and monitoring equipment installations in the surrounding Antelope Valley area. This report includes extended abstracts of the oral presentations summarizing the results of ongoing research that were given at that second meeting.

The report includes case studies of land subsidence and aquifer-system deformation resulting from karst processes, fluid withdrawal, and geothermal development. Several of the abstracts deal with various aspects of land subsidence and earth fissuring at Edwards Air Force Base that are resulting in extensive damage to runways used by military aircraft and the NASA Space Shuttle. Methods for monitoring land subsidence are described, including the application of two different techniques for using Global Positioning System technology for the rapid and accurate measurement of changes in land-surface altitude. Measurement techniques and theories describing the processes governing the formation of earth fissures are presented. Ongoing research into the development of numerical techniques for simulation and quantification of 3-dimensional aquifer-system deformation are also presented. Recently developed analytical and numerical techniques for the simulation of aquifer-system compaction due to fluid withdrawal are summarized.

The information presented in this report should help expand the scientific basis for management decisions to mitigate or control the effects of land subsidence. The papers describing the results of these studies provide an excellent cross section of ongoing research in aquifer mechanics and land subsidence and also form an assessment of the current technology and "state of the science." The analytical and interpretive methods described in this report will be useful to scientists involved in studies of ground-water hydraulics and aquifer-system deformation.